



Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Percentage of microbeads in pelagic microplastics within Japanese coastal waters

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ARTICLE INFO

Article history:

Received 27 March 2016

Received in revised form 4 June 2016

Accepted 7 June 2016

Available online xxx

Keywords:

Microbeads

Microplastics

Personal care and cosmetic products

ABSTRACT

To compare the quantity of microbeads with the quantity of pelagic microplastics potentially degraded in the marine environment, samples were collected in coastal waters of Japan using neuston nets. Pelagic spherical microbeads were collected in the size range below 0.8 mm at 9 of the 26 stations surveyed. The number of pelagic microbeads smaller than 0.8 mm accounted for 9.7% of all microplastics collected at these 9 stations. This relatively large percentage results from a decrease in the abundance of microplastics smaller than 0.8 mm in the upper ocean, as well as the regular loading of new microbeads from land areas, in this size range. In general, microbeads in personal care and cosmetic products are not always spherical, but rather are often a variety of irregular shapes. It is thus likely that this percentage is a conservative estimate, because of the irregular shapes of the remaining pelagic microbeads.

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1. Introduction

Plastic litter that has degraded into fragments smaller than 5 mm in diameter is referred to as microscopic plastics (Thompson et al., 2004) or microplastics (e.g., Ryan et al., 2009; “secondary microplastics” according to Cole et al., 2011). It is thought to be impossible to retrieve these small fragments, once they have spread widely across the world's oceans. In fact, microplastics have been reported in the open oceans (Thompson et al., 2004; Cózar et al., 2014; Eriksen et al., 2014), in marginal seas at mid-latitudes (Isobe et al., 2015; Barboza and Gimenez, 2015; Deudero and Alomar, 2015), and in the Arctic Ocean (Lusher et al., 2015), as well as in coastal waters (Reisser et al., 2013; Isobe et al., 2014). Microplastics may act as transport vectors of chemical pollutants into the marine ecosystem, owing to the absorption of pollutants onto the plastic surface (Mato et al., 2001; Teuten et al., 2009) and the ingestion of tiny microplastics by organisms as small as zooplankton (Desforges et al., 2015). Such pollution will be unavoidable in the future if microplastics continue to be discharged into the oceans.

Industry uses the term “microbeads” to describe microplastic particles present as ingredients in personal care and cosmetic products (PCCPs); they are also called microspheres, nanospheres, plastic particulates (UNEP, 2015; Napper et al., 2015), and primary microplastics (Cole et al., 2011). Likewise, microbeads have been recognized as a source of marine plastic pollution (UNEP, 2015). Indeed, the environmental damage of plastic scrubbers in skin cleansers was pointed out by Zitko and Hanlon (1991); Gregory (1996), and Fendall and Sewell (2009). A recent experimental trial demonstrated that microbeads act

as transport vectors of sorbed chemicals (Napper et al., 2015). However, to date, there are few peer-reviewed publications on suspected microbeads collected in oceans and/or lakes. An example of such research is that of Eriksen et al. (2013), who found colored spherical plastic particles during an expedition to the Laurentian Great Lakes. The plastic particles they found were of similar size, shape, color, and polymer materials to microbeads contained in facial cleansers, and thus, the particles were likely derived from PCCPs. However, it is a difficult task to identify microbeads (primary microplastics) in the environment unless they take a spherical shape unlikely to be formed by natural degradation, because microbeads cannot be tracked from their sources. The present study also uses the term “suspected microbeads” in line with Eriksen et al. (2013).

In the present study, pelagic microbeads were collected in Japan's coastal waters to compare the microbeads' quantity with that of pelagic microplastics collected concurrently. If microbeads account for a nonnegligible fraction of pelagic microplastics in nature, microbeads are likely to contribute to present marine plastic pollution to some extent. Even if their fraction is negligibly small, they may still have an important environmental effect in the future, in the absence of public awareness and/or legal regulation.

As mentioned above, there is no way of distinguishing microbeads from secondary microplastics in nature, unless they take a spherical shape unlikely to be formed by natural degradation. The sizes and elemental composition (mostly polyethylene) of microbeads do not allow the microbeads to be distinguished from secondary microplastics that usually have similar sizes (shown later in Fig. 3) and elemental composition (Reisser et al., 2013; Isobe et al., 2014); thus, microbeads were only identified in terms of their spherical shape. In the following analyses, spherical pellets (nurdles) are not included because they are

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typically at least several millimeters in diameter and thus much larger than the microbeads collected (shown later in Fig. 3). However, as pointed out by Zitko and Hanlon (1991); Gregory (1996); Fendall and Sewell (2009), and Napper et al. (2015), microbeads in PCCPs are not always spherically shaped; microbeads in PCCPs available in Japanese supermarkets, pharmacies, etc. also have a variety of irregular shapes (shown later in Fig. 4). The present study thus provides a conservative estimate of the microbead percentage in pelagic microplastics in the coastal waters of Japan. In the following descriptions, the term “microplastics” (without the terms “primary” or “secondary”) includes both microbeads and secondary microplastics, unless otherwise stated.

2. Materials and methods

2.1. Field surveys

A field campaign to sample microplastics was conducted by the Ministry of Environment, Japan, from 15 September to 30 October 2015. Sampling surveys were conducted using fishery boats, at 26 stations in Tokyo Bay, Suruga Bay, Ise Bay, and the Seto Inland Sea, Japan (Fig. 1). Neuston nets (5552; RIGO Co., Ltd., Tokyo, Japan) were used to collect small plastic fragments near the sea surface. The mouth dimensions, length, and mesh size of each net were 75×75 cm, 3 m, and

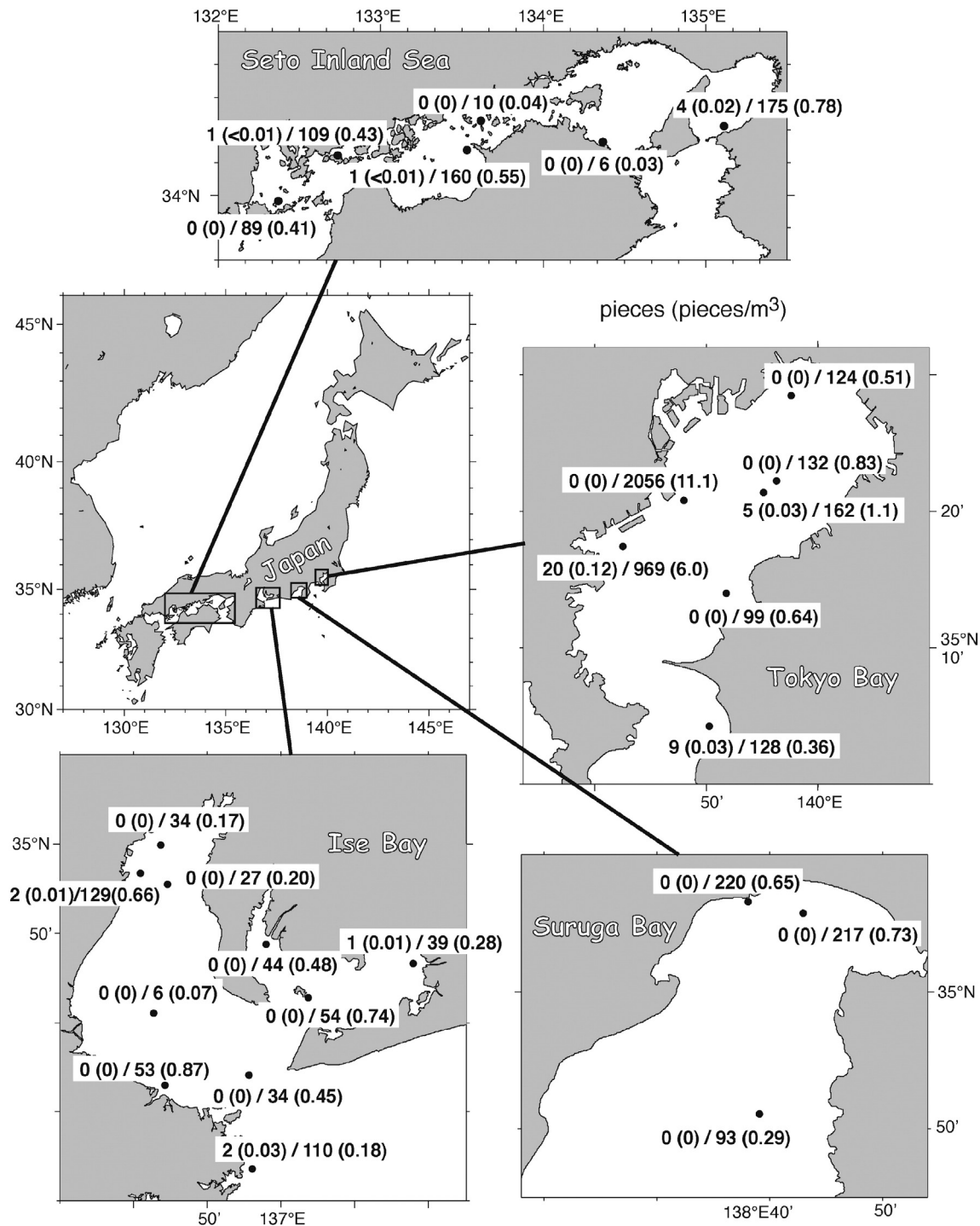


Fig. 1. Sampling stations. The values next to dots are quantities (concentrations) of microbeads, followed by those of microplastics, at each station.

0.35 mm, respectively. Thus, the lower limit of the size of microplastics discussed in the present study was determined by this mesh size. Boats towed the neuston nets for 20 min at a constant speed of 2–3 knots. A flow meter (5571A; RIGO Co., Ltd.) was installed at the mouths of the nets to measure the water volume that passed through during the sampling period. This ensured that the estimate of microplastics collected would be accurate; ocean/tidal current speeds in the coastal waters frequently exceed 1 m/s (~2 knots). According to the flow meter data, the water volume averaged over all sampling stations was 191 m³, and the standard deviation of the water volume was 88 m³. The concentration of the microplastics has been estimated at O(1) pieces/m³ around Japan (Isobe et al., 2014; Isobe et al., 2015), and it was thus anticipated that the seawater could be surveyed with a large volume sufficient to collect numerous pelagic microplastics at all stations.

2.2. Measurements of small plastic fragments

To distinguish plastic fragments from other suspended matter in seawater samples, the small fragments collected at all stations were sent to our laboratory at Kyushu University. All samples were observed on a monitor display via a Universal Serial Bus camera (HDCE-20C; AS ONE Corporation, Osaka, Japan) attached to a stereoscopic microscope (SZX7; Olympus Corporation, Tokyo, Japan) and identified visually by their color and shape. When fragments were too small for visual differentiation between microplastics and other suspended matters, polymer types of material were identified using a Fourier-transform infrared spectrophotometer (FT-IR alpha; Bruker Optics K.K., Tokyo, Japan). Lines (probably fishing lines), expanded-polystyrene particles, and biological elements were removed before further analysis.

The number of remaining pieces (particle count; hereafter, referred to as the “quantity”) in each size range was counted at increments of 0.1 mm, for microplastics smaller than 5 mm. The sizes were defined by the longest length of each irregularly shaped fragment, measured using image-processing software (ImageJ downloaded from [\[imagej.nih.gov\]\(http://imagej.nih.gov\)\). The quantities within each size range were thereafter divided by water volumes, measured by the flow meter at each sampling station, to convert them to the quantity per unit seawater volume \(hereafter, “concentration” with a unit of pieces m⁻³\). The total concentration of microplastics was computed by integrating the concentrations of fragments with sizes from 0.3 to 5 mm. Irrespective of their size, color, and surface roughness, spherical particles \(except resin pellets\) were regarded as microbeads derived from PCCPs \(Fig. 2\).](http://</p>
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For reference, microbeads contained in facial cleansers available in Japanese supermarkets, pharmacies, etc. were also investigated. For comparison of the sizes and shapes of these particles and microbeads collected in the actual oceans, facial cleansers containing polyethylene particles (listed in their ingredients) for four major brands were purchased at a supermarket close to the Kyushu University in Kasuga, Fukuoka Prefecture. The specific brand names are not of particular relevance; they are hereinafter referred to as brands A–D. Thirty spherical particles were extracted from each facial cleanser, and their quantities were measured for each size range in the same manner as microplastics collected in the oceans.

3. Results

Spherical polyethylene particles (suspected microbeads) were found at 9 of the 26 stations (see Fig. 1 for quantities and concentrations at each station). In terms of shape, only 45 of 4929 (0.9%) microplastic particle smaller than 5 mm were identified as microbeads (Fig. 2). The quantity of microbeads collected in the oceans is likely to depend on freshwater discharge from the nearest river, oceanic fronts (hence, surface convergent flows) close to the stations, and wind- and wave-induced oceanic turbulence in the upper oceans (Kukulka et al., 2012; Reisser et al., 2015; Isobe et al., 2015) as well as the concentration of microbeads. It is thus difficult to directly compare the quantities of microbeads between stations in coastal waters. Nonetheless, it is noted that the quantity of microbeads was one order of magnitude

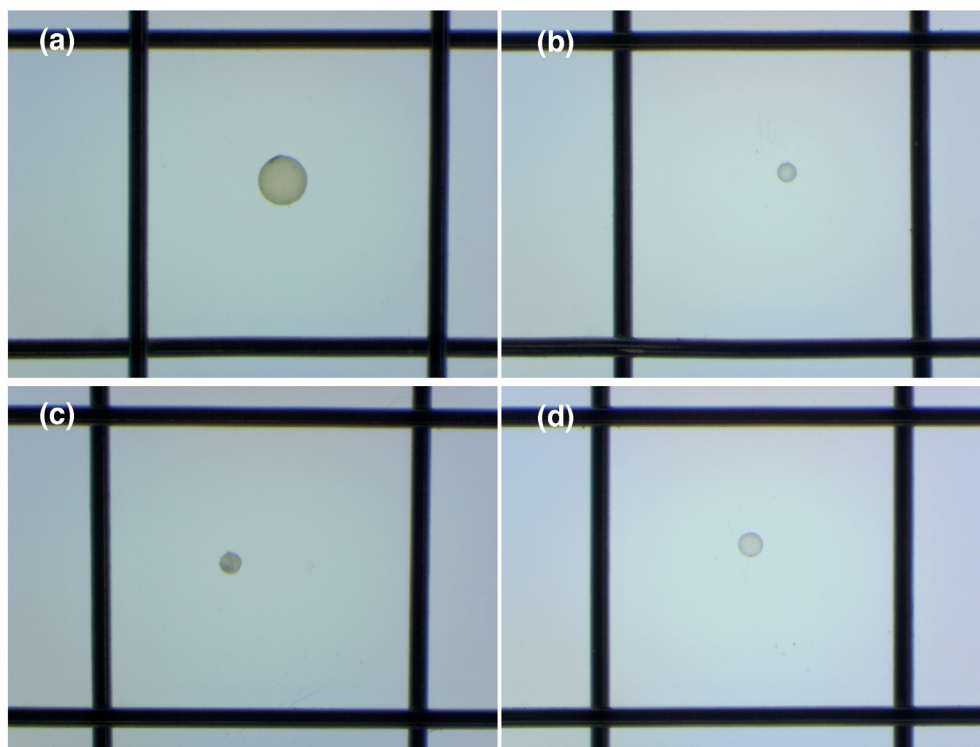


Fig. 2. Microscopic photographs of microbeads collected in Tokyo Bay (a and b), Ise Bay (c), and the Seto Inland Sea (d). Also shown on the photographs are boxes with sides of 5 mm. The thickness of the wires is 0.3 mm.

larger in Tokyo Bay (34 pieces in total) than in the other areas (Fig. 1). The suggestion is that numerous microbeads leak into Tokyo Bay, owing to the variety of PCCPs used by the largest population in Japan (~30% of the total population of Japan).

As shown by Isobe et al. (2014, 2015) and C  zar et al. (2014), the quantity of microplastics exponentially increases as the particle size of microplastics decreases (Fig. 3a). This is reasonable because a large microplastic particle degrades to multiple small pieces, while keeping its original volume and weight. Of particular interest, the concentrations of microplastics decreased rapidly at sizes less than 0.8 mm (Fig. 3a). Isobe et al. (2015) mentioned that the removal of microplastic particles of similar sizes in the upper ocean might result from the downward intrusion of fragments, which are prevented from ascending by friction. In addition, they mentioned that a descent due to biofouling and ingestion by marine biota is a possible cause. In-depth examinations are required to determine the definitive cause(s) of this rapid decrease.

There is a possibility that tiny microplastics slipped through the neuston net, because they were smaller than the mesh size (0.35 mm) and/or tiny pieces might have been overlooked during visual extraction from sampled seawater in the laboratory. However, the above situation was unlikely to occur because of the following reasons. At 9 stations where suspected microbeads could be collected, the size distribution

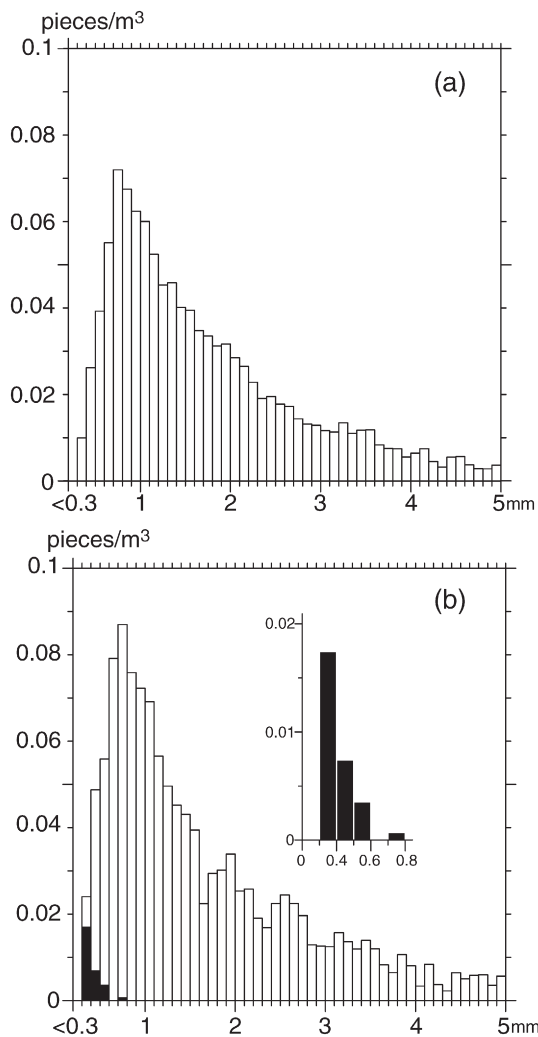


Fig. 3. Size distribution of microplastics at all 26 stations (upper panel) and at 9 stations (lower panel) where pelagic microbeads were collected. The bars indicate the concentration in each size range on the abscissa. The intervals of size ranges are 0.1 mm. The concentrations of microbeads (black bars) are enlarged in panel (b).

of microplastics decreased prominently below 0.8 mm (Fig. 3b). Nevertheless, microplastics collected, thought to be of microbeads origin, were more abundant below a size of 0.8 mm (Fig. 3b). If the rapid decrease in microplastic abundance was the result of microplastics being unable to be caught by the neuston nets and/or being overlooked in the laboratory (as well as the downward intrusion by oceanic turbulence), the abundance of microbeads would also decrease in the same manner. However, the abundance of pelagic microbeads actually increased in the size range less than 0.8 mm, in which the abundance of microplastics rapidly decreased (Fig. 3b). Consequently, the percentage (i.e., relative quantity) of microbeads becomes larger than that of irregularly shaped microplastics in the size range between 0.3 and 0.4 mm.

4. Discussion

Pelagic spherical microbeads found in the coastal waters of Japan are likely to have originated from PCCPs available in Japanese supermarkets, pharmacies, etc. However, it is difficult to identify the specific products from which these microbeads originated, because microbeads are widely used in a variety of PCCPs, including deodorants, shampoos, conditioners, shower gels, and lipsticks (UNEP, 2015). Thus, the microbeads extracted from facial cleansers (Fig. 4a and b) provided us with only an example of typically used PCCPs in Japan. Nonetheless, the similarity of the spherical shape and sizes can be seen in Figs. 2, 4a and b. In addition, the size distribution (Fig. 5) showed that microbeads in facial cleansers were of a similar size range as the pelagic microbeads in the ocean (Fig. 3). PCCP-derived microbeads at a size that makes them available to be ingested by marine biota leak into coastal waters. These microbeads are likely to be transported to wastewater treatment plants, where some will be captured by the filtration systems. However, owing to the small sizes of microplastics, it is anticipated that a substantial proportion of microplastics will pass through filtration systems and enter marine environments (Fendall and Sewell, 2009; Napper et al., 2015). It is noted that, as shown in previous studies (Zitko and Hanlon, 1991; Gregory, 1996; Fendall and Sewell, 2009; Napper et al., 2015), microbeads in PCCPs are not always spherical, but have a variety of irregular shapes. In fact, it was found that there was a mix of spherical and irregularly shaped microbeads in the facial cleanser of brand C (Fig. 4c), while all microbeads in brand D had irregular shapes (Fig. 4d).

The percentage of microplastics that are microbeads was computed using the concentration averaged over the 9 stations (Table 1; also showing the percentage averaged over all 26 stations). The percentage in the size range of the pelagic microbeads less than 0.8 mm was 9.7% (microplastics smaller than 5 mm, 2.3%), which may be larger than projected. As mentioned above, the abundance of microbeads did not rapidly decrease in the size range below 0.8 mm, in which the abundance of microplastics rapidly decreased. The percentage of microbeads thus increases as the size decreases; the percentage in each size range shows that the abundance of microbeads reached 71.5% of the abundance of pelagic microplastics with sizes ranging from 0.3 to 0.4 mm. In general, spherical (i.e., undegraded) microbeads are likely to have been sourced from land areas close to the observation stations. In fact, the largest concentration was obtained in Tokyo Bay, around which PCCPs are consumed by the largest population in Japan. It is therefore suggested that these microbeads were collected, even in the smaller size range, while the pelagic microplastics might disappear after drifting a long time, sufficient for biofouling and/or ingestion by biota. In the present study, however, it was not possible to further explore the cause(s) of disappearance of tiny microplastics and appearance of microbeads, respectively.

5. Conclusion

Suspected microbeads (smaller than 0.8 mm), found in the pelagic zone in the ocean, accounted for 9.7% of all microplastics collected from 9 stations at which microbeads were collected in the upper

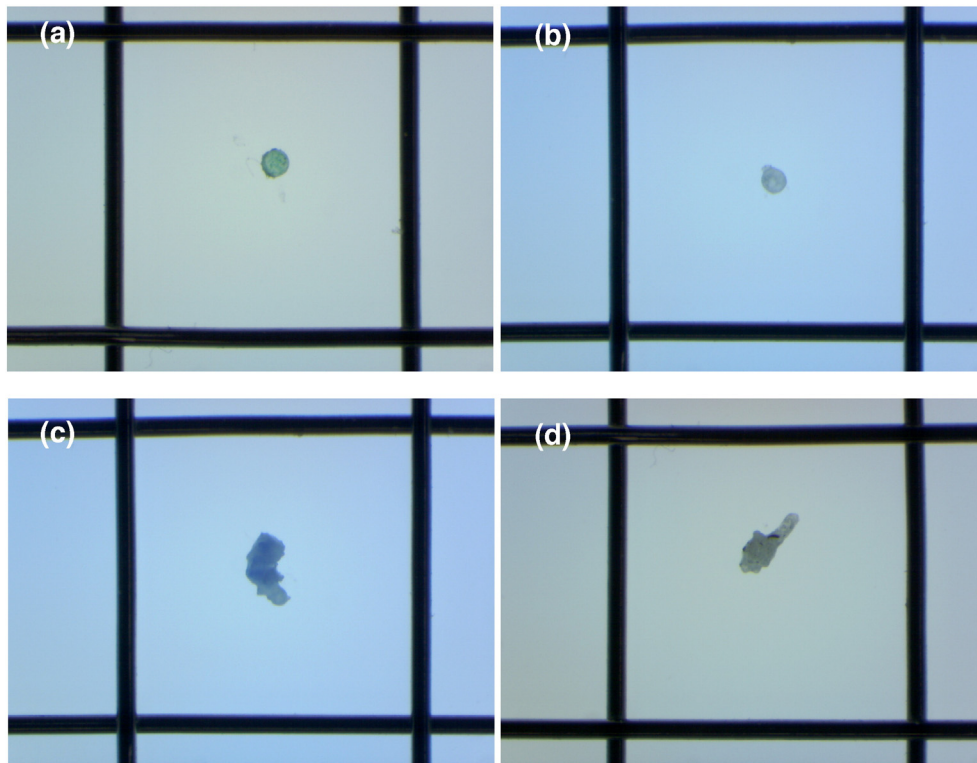


Fig. 4. Microscopic photographs of microbeads extracted from facial cleansers of brands A (a), B (b), C (c), and D (d).

ocean (within 0.75 m of the sea surface). The percentage averaged over 26 stations, including stations at which microbeads were not collected, decreased to 3.4%, but was still a nonnegligible fraction of microplastics collected in the coastal waters of Japan. This relatively large percentage results from the rapid decrease in abundance of microplastics smaller than 0.8 mm in the upper oceans, which are partly replaced with microbeads used in everyday life. In fact, it was found that there was a mix of spherical and irregularly shaped microbeads in PCCPs (Fig. 4c and d). The samples collected in the oceans consisted partly of

suspected microbeads and, thus, the percentage was underestimated to some extent, because of the remaining pelagic microbeads with irregular shapes. It should therefore be recognized that the title of the paper authored by Fendall and Sewell (2009), “Contributing to marine pollution by washing your face”, is not warning not just for the future but also for the present.

Acknowledgments

The authors sincerely thank the Ministry of the Environment, Japan, for providing sampling data of microplastics, Universe and Naigai Map Production for their intensive field surveys, and Sayaka Yamaguchi, Kayoko Takashima, and Masahiro Motoi for their patience in measuring small plastic fragments in the laboratory. Thanks are also extended to the journal reviewer for his/her help in improving the manuscript. Part of this research was supported by the Environmental Research and Technology Development Fund (4-1502) of the Ministry of the Environment.

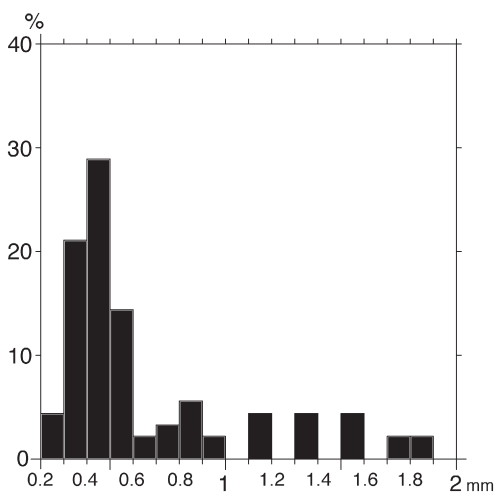


Fig. 5. Size distributions of spherical microbeads extracted from facial cleansers of brands A, B, and C. The bars indicate the percentage of microbeads quantities (particle count) in each size range for 90 samples. The intervals of size ranges are 0.1 mm.

Table 1

Concentration fractions computed by dividing the microbead concentration by the microplastic concentration. The left column gives the percentages averaged over 9 stations at which both microplastics and microbeads were collected. The right column gives the percentages averaged over 26 stations including those at which microbeads were not collected.

Size range	9 stations %	26 stations %
<0.8 mm	9.7	3.4
<5 mm	2.3	0.8

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